

Within-Plant Distribution of *Frankliniella* species (Thysanoptera: Thripidae) and *Orius insidiosus* (Heteroptera: Anthocoridae) in Field Pepper

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ABSTRACT We evaluated the within-plant distribution of *Frankliniella* spp. and the predator *Orius insidiosus* (Say) in pepper (*Capsicum annum* L.), over a range of field conditions, and we conducted behavioral experiments to examine the time budgets of *F. occidentalis* (Pergande) and *F. tritici* (Fitch) females on pepper plant parts. In the field experiments *Frankliniella* species composition varied by season and location. Still, all populations of thrips and *O. insidiosus* in untreated and insecticide-treated pepper were highly concentrated in the flowers, with 82–99% of individuals of each taxa found in flowers. This preference for flowers was corroborated by laboratory-choice experiments. Adult females of *F. occidentalis* and *F. tritici* showed a strong preference for pepper flowers over leaves and buds. In laboratory observations, females of *F. occidentalis* spent 3.6× as much time on flowers as on all other plant parts, and females of *F. tritici* spent over 6.3× as much time on flowers as on all other plant parts. Therefore, the concentration of these thrips in flowers appears to be behaviorally based and not an artifact of insecticide applications or sampling. Using estimates of populations from flowers of field pepper is sufficient for understanding the local dynamics of *Frankliniella* spp. and the predator *O. insidiosus*, and for estimating the benefits of biological control in scouting programs based on predator to prey ratios.

KEY WORDS pepper, Anthocoridae, Thripidae, within plant distribution, biological control

THRIPS IN THE GENUS *Frankliniella* (Thysanoptera: Thripidae) are ubiquitous, polyphagous pests of vegetable, fruit and ornamental crops. Feeding by these thrips can result in distortion, discoloration, stunting, and silencing of foliage, flowers and fruits of crops (Childers 1997). An even greater concern with *Frankliniella* thrips is the ability of some species to transmit pathogens in the genus *Tospovirus* (Bunyaviridae) to a wide variety of plant species (Sether and Deangelis 1992, Ullman et al. 1997). These plant pathogens are especially difficult to control in crops grown in mild climates and greenhouses, which favor nearly continuous cropping and year-round presence of thrips vector populations. Direct feeding damage and pathogen transmission by thrips cost growers billions of dollars worldwide in control measures and lost productivity (Ullman et al. 1997).

Not only do species of *Frankliniella* feed on many different species of host plants, they are able to feed in different microhabitats within a particular host plant (Kirk 1997, Mound 1997). The adults and larvae of *Frankliniella occidentalis* (Pergande) are most abundant in flowers of a variety of plants (Gonzalez and Wilson 1982, Pickett et al. 1988), but these patterns can be variable. For example, Higgins (1992) found the majority of *F. occidentalis* adults in flowers of greenhouse-grown peppers (*Capsicum annum* L.) and cucumbers (*Cucumis sativus* [L.]) but the majority of larvae on the leaves. In contrast, Tavella et al. (1996) showed that 96% of adult and larval *Frankliniella* spp. occurred in flowers of greenhouse-grown pepper. The factors leading to such variation among studies are unknown. Although a similar flower-biased distribution to that found by Tavella et al. (1996) is believed to occur in field-grown pepper (Funderburk et al. 2000, Ramachandran et al. 2001), extensive studies of within-plant patterns of distribution and the behavioral mechanisms producing those distributions have not been conducted.

Understanding the within plant distribution of thrips and the underlying behavioral mechanisms is of particular relevance for understanding how crop damage occurs, planning efficient sampling strategies, and

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implementing pest management tactics. The ability of thrips to deplete yields and render some crops uneconomical has demanded that effective pest management practices be developed. Attempts to control populations by regular insecticide applications have led to the development of resistance to most classes of insecticides (Immaraju et al. 1992). However, sustainable control may be achieved through the management of natural enemies. Anthocorid predators (Heteroptera: Anthocoridae) can be effective biological control agents of thrips in greenhouses (Brødsgaard and Enkegaard 1995, Tavella et al. 1996). Although their effectiveness in open field crops has only recently been studied, this recent research has revealed that *Orius insidiosus* (Say) is an effective predator of *F. occidentalis*, *F. tritici* (Fitch), and *F. bispinosa* (Morgan) in the flowers of field-grown pepper (Funderburk et al. 2000, Ramachandran et al. 2001).

Our study had two primary objectives. The first objective was to determine the within plant distribution of *Frankliniella* spp. of thrips and the key thrips predator *O. insidiosus* in field-grown pepper. In addition to behavioral alterations because of the presence of natural enemies (Coll and Izraylevich 1997), factors such as population density and migration are known to influence within-plant distributions among species of thrips (Shipp and Zariffa 1991, Theunissen and Legutowska 1991, Higgins 1992). Therefore, we evaluated patterns of distribution over a range of field conditions and insecticide use patterns. Insecticides were used to manipulate densities of thrips and *O. insidiosus* to determine if distributions of thrips and/or *O. insidiosus* change in the presence or absence of the other. The second objective was to evaluate the behavioral time budget of *F. occidentalis* and *F. tritici* on pepper. The behaviors of thrips are difficult to observe under field conditions; therefore thrips preferences were determined under optimal conditions (absence of predators, chemicals, and environmental stresses), in the laboratory.

Materials and Methods

Field Experiments. Sweet pepper ('Camelot') was planted at the North Florida Research and Education Center, Quincy, FL, during the fall 1998 and spring 1999, and in the spring 1999 in Riverview, FL. Quincy, Gadsden County, is located in the panhandle of northern Florida, and Riverview, Hillsborough County, is located in central Florida.

Pepper plants were grown according to standard horticultural practices, in raised beds covered with white plastic mulch in the fall experiment and black plastic mulch in the spring experiments. Different mulch colors are used as a typical production practice to regulate soil temperature. Each bed consisted of two linear rows of plants, with a 30-cm spacing between and within rows. Plastic mulch beds were spaced 0.9 m apart. Plants were irrigated based on the plant needs, through a trickle tube placed at the center of each bed. The design of each experiment was a randomized complete block with four replicates of each treatment.

Plants in the experiment conducted in the fall of 1998 in Quincy were transplanted on 12 August. Plot size was two adjacent beds, each 4-m long. Treatments included an untreated control, esfenvalerate (Asana 0.66 SC, DuPont, Wilmington, DE, at 0.057 kg [AI]/ha), and spinosad (Spintor 2 SC, Dow Agrosciences, Indianapolis, IN, at 0.076 kg [AI]/ha). Insecticide treatments were applied in a water solution at 180 liters/ha, with a gas pressurized backpack sprayer fitted with three hollow-cone nozzles (D7-45). Side nozzles were directed straight into the plants of the 2-row bed and a nozzle was placed over the top of the bed. Esfenvalerate is a pyrethroid toxic to a broad spectrum of arthropods. Spinosad is derived from the fermentation of *Saccharopolyspora spinosa* Mertz & Yao and has minimal negative effects on certain species of natural enemies, such as *O. insidiosus* (Eger et al. 1998, Elzen et al. 1998, Pietrantonio and Benedict 1999, Funderburk et al. 2000). Plots were treated on 14, 22, 28 September and 5, 12, and 19 October.

Five flowers, five flower buds, five leaves from the upper half of the plants, and five leaves from the lower half of the plants were randomly collected from each plot 1, 3, and 7 d after spraying. Samples were placed in vials containing 70% ethyl alcohol, and thrips and natural enemies were extracted under a stereomicroscope at 40 \times . Based on taxonomic characters, numbers of adult males and females of each thrips species in each sample were determined. Because larval thrips are not identifiable to species, they were counted as a group. The numbers of *O. insidiosus* and other predatory insects were also determined. Representative voucher specimens are deposited at the University of Florida, North Florida Research and Education Center, Quincy, FL.

Plants in the experiments conducted in the spring of 1999 were transplanted on 22 March in Quincy and on 29 March in Riverview. Plot size at Quincy was one bed 7.5 m long; plot size at Riverview was two adjacent beds each 6-m long. Treatments in both experiments consisted of the same chemicals and rates as the fall 1998 season, but also included acephate (Orthene 75SP, Valent, Walnut Creek, CA, at 0.85 kg [AI]/ha). Acephate is an organophosphate toxic to a broad spectrum of arthropods through direct contact and systemic activity. Dates of insecticide applications were 3, 10, 17, 24 May and 1, 8, 15 June in Quincy and 18, 25, April and 2, 9, 16 May in Riverview. Sampling procedures were the same as described previously for the 1998 season.

A split-plot analysis of variance (ANOVA), at $\alpha = 0.05$, was used to test for significant effects of insecticide treatment and plant part on the seasonal total numbers of thrips and *O. insidiosus*. Before analysis, data were examined to determine that assumptions for ANOVA were satisfied. Insecticide treatments were the whole plots and plant parts were the subplots. Means were separated by least squares means (SAS Institute 1990) when the ANOVA was significant.

Behavioral Assays. Feral adults of *F. occidentalis* and *F. tritici* were collected from wild host plants, and placed on green bean pods for at least 24 h. Individual adult

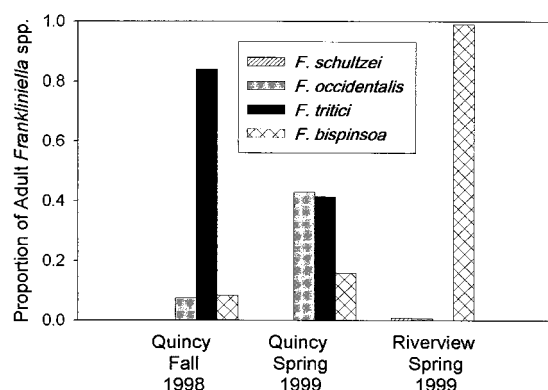


Fig. 1. Composition of *Frankliniella* spp. adults in samples of untreated pepper in experiments conducted in Quincy (fall: $n = 247$; spring: $n = 920$) and Riverview ($n = 1749$), FL.

females were placed into a petri dish between one leaf, one bud, and one flower of 'Camelot' sweet pepper. Thrips were observed under a videomicroscope at $40\times$ for 1 h. Pepper plants were maintained in a greenhouse, and plant parts from the same plant were used to observe both *F. occidentalis* and *F. tritici* on the same day ($n = 12$ per species). The time spent in different behaviors and location of events were recorded, using Observer v. 2.0 software (Noldus Information Technology Inc., Sterling, VA). Behavior was categorized as feeding, resting, or walking. A feeding session occurred when an individual stood still with its forelegs apart, antennae still, usually nodding its head up and down, and probing with its mandible. Resting included when a thrips was quiescent or grooming. Because thrips rarely engaged in locomotion other than walking, all types of locomotion were classified as walking. Rarely observed behaviors were combined into "other" behaviors. Occasionally, thrips moved deep into the flower. This time was categorized as unaccounted, and later combined with "other" time for analyses. Locations were on flower, bud or leaf, or off plant parts.

Time spent in each behavior and location was converted to a proportion of the total observation time. A multivariate ANOVA (MANOVA) was used to compare the time budgets of *F. tritici* and *F. occidentalis* on pepper (Aebischer et al. 1993, Cisneros and Rosenheim 1998). These proportional data were logarithmically transformed to satisfy the assumption of normality. Appropriate univariate ANOVAs were performed to compare proportion of time spent in different behaviors, such as feeding and locomotion, given that a significant MANOVA indicated there was a significant difference in time budgets between the species.

Results

Field Experiments. The demography of thrips species varied by site and time of year. Virtually all of the adults collected at Riverview were *F. bispinosa* (Fig. 1). Other species collected were *F. occidentalis* and *F.*

schultzei (Trybom) (collectively $<1\%$ of the adults in samples of untreated pepper). Species collected in Quincy were *F. occidentalis*, *F. tritici*, and *F. bispinosa*, but the species composition in untreated pepper differed greatly between the spring and fall seasons (Fig. 1). Although each species was found commonly in the spring, *F. tritici* comprised 84% of the adults collected in untreated pepper in the fall. Over 99% of all predators collected in untreated pepper of each experiment were adults and nymphs of *O. insidiosus*.

Adults and larvae of each *Frankliniella* species as well as adults and nymphs of *O. insidiosus* were highly concentrated in the pepper flowers (Table 1; Fig. 2). Numbers on the leaves and buds were always extremely low; therefore, the pooled means for these plant parts are shown. $\approx 98\%$ of the total thrips in the spring at Quincy ($n = 6,566$) and Riverview ($n = 10,117$) were found in the flowers (Fig. 2). The percentage collected in the flowers in the fall at Quincy was 92% ($n = 974$). Over 95% of the adults and nymphs of *O. insidiosus* were collected in the flowers in the spring at Quincy and Riverview (Fig. 2). There was $\approx 71\%$ of the total *O. insidiosus* collected in the fall at Quincy in flowers.

Significant interactions between insecticide treatments and plant parts on the abundance of thrips and *O. insidiosus* occurred in nearly all cases (Table 1). In these cases, the interactions reflect the distribution of the insects. The abundances of thrips and *O. insidiosus* on plant parts other than the flower were so low that insecticide treatments would result in minimal differences occurring. However, insecticide treatments did produce significant differences in insect abundances in flowers (Table 1; Figs. 3-5). In cases where significant plant part by insecticide interactions occurred, simple effects of insecticide treatments within flowers only were examined.

The insecticides tended to have species-specific effects. The abundance of *F. occidentalis* in experiments at Quincy was significantly higher in plots treated with either esfenvalerate or acephate than in untreated plots or plots treated with spinosad (Table 1; Figs. 3 and 4). Numbers of *F. occidentalis* at Quincy were significantly lower both seasons in pepper treated with spinosad compared with untreated pepper (Table 1; Figs. 3 and 4). Possibly because of their variable, low overall numbers, no differences among insecticide treatments were found for *F. bispinosa* and *F. tritici* adults, and *Frankliniella* spp. larvae during the fall season in Quincy (Table 1; Fig. 3). In contrast during the spring season in Quincy, acephate and esfenvalerate reduced numbers of *F. tritici* and *F. bispinosa* in the flowers compared with untreated plots (Table 1; Fig. 4). A similar pattern for *F. bispinosa* occurred during the spring season in Riverview (Table 1; Fig. 5). During the spring season in Quincy, numbers of larval thrips in plots treated with acephate or esfenvalerate were significantly lower than numbers in untreated plots or plots treated with spinosad (Table 1; Fig. 4). Larvae were least abundant in the spinosad treated plots. However, larvae were significantly more abun-

Table 1. Split plot ANOVA showing effects of plant parts and insecticide treatments on *Frankliniella* species and *O. insidiosus* abundance in field pepper

| Season | Location | Species | Source of Variation | df | F | P |
|-------------|---------------|-----------------------------|--|----|--------|---------|
| Fall 1998 | Quincy, FL | <i>F. occidentalis</i> | Insecticide | 2 | 5.13 | 0.050 |
| | | | Block \times Insecticide ^a | 6 | | |
| | | | Plant Part | 3 | 43.10 | <0.0001 |
| | | | Plant Part \times Insecticide | 6 | 7.80 | 0.0001 |
| | | | Block \times Plant Part (Insecticide) ^b | 27 | | |
| Fall 1998 | Quincy, FL | <i>F. tritici</i> | Insecticide | 2 | 1.45 | 0.31 |
| | | | Block \times Insecticide ^a | 6 | | |
| | | | Plant Part | 3 | 37.04 | <0.0001 |
| | | | Plant Part \times Insecticide | 6 | 1.19 | 0.34 |
| | | | Block \times Plant Part (Insecticide) ^b | 27 | | |
| Fall 1998 | Quincy, FL | <i>F. bispinosa</i> | Insecticide | 2 | 1.92 | 0.226 |
| | | | Block \times Insecticide ^a | 6 | | |
| | | | Plant Part | 3 | 17.22 | <0.0001 |
| | | | Plant Part \times Insecticide | 6 | 1.29 | 0.29 |
| | | | Block \times Plant Part (Insecticide) ^b | 27 | | |
| Fall 1998 | Quincy, FL | <i>Frankliniella</i> Larvae | Insecticide | 2 | 1.88 | 0.23 |
| | | | Block \times Insecticide ^a | 6 | | |
| | | | Plant Part | 3 | 42.07 | <0.0001 |
| | | | Plant Part \times Insecticide | 6 | 2.68 | 0.36 |
| | | | Block \times Plant Part (Insecticide) ^b | 27 | | |
| Fall 1998 | Quincy, FL | <i>O. insidiosus</i> | Insecticide | 2 | 3.16 | 0.11 |
| | | | Block \times Insecticide ^a | 6 | | |
| | | | Plant Part | 3 | 16.41 | <0.0001 |
| | | | Plant Part \times Insecticide | 6 | 4.58 | 0.002 |
| | | | Block \times Plant Part (Insecticide) ^b | 27 | | |
| Spring 1999 | Quincy, FL | <i>F. occidentalis</i> | Insecticide | 3 | 18.36 | 0.0004 |
| | | | Block \times Insecticide ^a | 9 | | |
| | | | Plant Part | 3 | 963.47 | <0.0001 |
| | | | Plant Part \times Insecticide | 9 | 27.77 | <0.0001 |
| | | | Block \times Plant Part (Insecticide) ^b | 36 | | |
| Spring 1999 | Quincy, FL | <i>F. tritici</i> | Insecticide | 3 | 1.50 | 0.28 |
| | | | Block \times Insecticide ^a | 9 | | |
| | | | Plant Part | 3 | 632.91 | <0.0001 |
| | | | Plant Part \times Insecticide | 9 | 2.78 | 0.014 |
| | | | Block \times Plant Part (Insecticide) ^b | 36 | | |
| Spring 1999 | Quincy, FL | <i>F. bispinosa</i> | Insecticide | 3 | 6.51 | 0.012 |
| | | | Block \times Insecticide ^a | 9 | | |
| | | | Plant Part | 3 | 280.34 | <0.0001 |
| | | | Plant Part \times Insecticide | 9 | 7.94 | <0.0001 |
| | | | Block \times Plant Part (Insecticide) ^b | 36 | | |
| Spring 1999 | Quincy, FL | <i>Frankliniella</i> Larvae | Insecticide | 3 | 29.03 | <0.0001 |
| | | | Block \times Insecticide ^a | 9 | | |
| | | | Plant Part | 3 | 424.36 | <0.0001 |
| | | | Plant Part \times Insecticide | 9 | 13.45 | <0.0001 |
| | | | Block \times Plant Part (Insecticide) ^b | 36 | | |
| Spring 1999 | Quincy, FL | <i>O. insidiosus</i> | Insecticide | 3 | 18.59 | 0.0003 |
| | | | Block \times Insecticide ^a | 9 | | |
| | | | Plant Part | 3 | 382.25 | <0.0001 |
| | | | Plant Part \times Insecticide | 9 | 15.55 | <0.0001 |
| | | | Block \times Plant Part (Insecticide) ^b | 36 | | |
| Spring 1999 | Riverview, FL | <i>F. occidentalis</i> | Insecticide | 3 | 4.01 | 0.046 |
| | | | Block \times Insecticide ^a | 9 | | |
| | | | Plant Part | 3 | 12.96 | <0.0001 |
| | | | Plant Part \times Insecticide | 9 | 4.69 | 0.0004 |
| | | | Block \times Plant Part (Insecticide) ^b | 36 | | |
| Spring 1999 | Riverview, FL | <i>F. schultzei</i> | Insecticide | 3 | 3.26 | 0.737 |
| | | | Block \times Insecticide ^a | 9 | | |
| | | | Plant Part | 3 | 6.40 | 0.0014 |
| | | | Plant Part \times Insecticide | 9 | 3.86 | 0.0017 |
| | | | Block \times Plant Part (Insecticide) ^b | 36 | | |
| Spring 1999 | Riverview, FL | <i>F. bispinosa</i> | Insecticide | 3 | 13.79 | 0.001 |
| | | | Block \times Insecticide ^a | 9 | | |
| | | | Plant Part | 3 | 223.45 | <0.0001 |
| | | | Plant Part \times Insecticide | 9 | 12.11 | <0.0001 |
| | | | Block \times Plant Part (Insecticide) ^b | 36 | | |
| Spring 1999 | Riverview, FL | <i>Frankliniella</i> Larvae | Insecticide | 3 | 27.53 | <0.0001 |
| | | | Block \times Insecticide ^a | 9 | | |
| | | | Plant Part | 3 | 302.15 | <0.0001 |
| | | | Plant Part \times Insecticide | 9 | 14.00 | <0.0001 |
| | | | Block \times Plant Part (Insecticide) ^b | 36 | | |
| Spring 1999 | Riverview, FL | <i>O. insidiosus</i> | Insecticide | 3 | 6.78 | 0.01 |
| | | | Block \times Insecticide ^a | 9 | | |
| | | | Plant Part | 3 | 50.58 | <0.0001 |
| | | | Plant Part \times Insecticide | 9 | 5.39 | 0.0001 |
| | | | Block \times Plant Part (Insecticide) ^b | 36 | | |

^a Error term for the whole plot insecticide treatment effect.
^b Error term for the subplot plant part treatment effect and plant part \times insecticide effect.

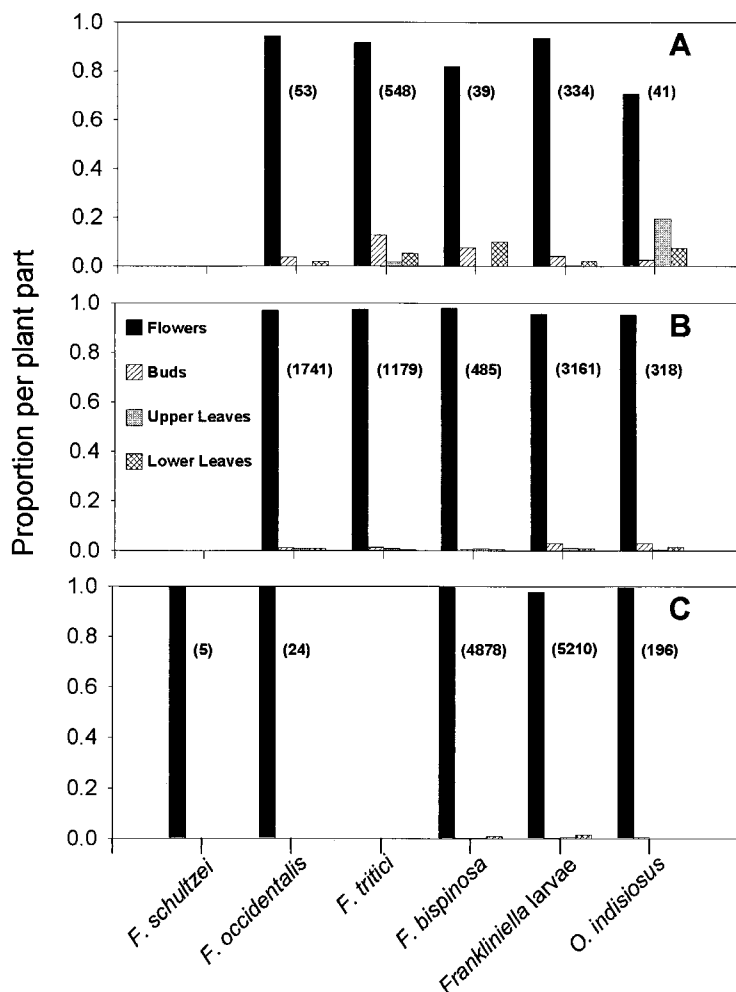


Fig. 2. Proportion of *Frankliniella* spp. and *O. insidiosus* on the flowers, buds, upper leaves, and lower leaves of pepper from samples collected in experiments conducted during the fall 1998 in Quincy, FL (A), and during the spring 1999 in Quincy (B) and Riverview, FL (C). Numbers in parentheses are totals for each taxon.

dant in the untreated plots than in any of the insecticide treated plots in Riverview (Table 1; Fig. 5).

The abundance of *O. insidiosus* was affected by insecticide treatments (Table 1; Figs. 3–5). Esfenvalerate and acephate suppressed populations of *O. insidiosus* in the flowers in each experiment compared with untreated plots. Spinosad had a less detrimental impact on *O. insidiosus* compared with these other insecticides.

Behavioral Assays. In the laboratory choice experiments, females of both *F. occidentalis* and *F. tritici* demonstrated a preference for flowers compared with buds and leaves on pepper (Fig. 6). There was a significant difference in the overall time budgets for the two species (Wilks lambda = 0.428, $P = 0.05$). On average, females of *F. occidentalis* spent $70.1 \pm 5.3\%$ of the time on the flower compared with $59.6 \pm 8.7\%$ of the time for females of *F. tritici*. Females of *F. occi-*

dentalis did spend more time on the buds and leaves ($17.0 \pm 2.5\%$ of the time) than did females of *F. tritici* ($8.1 \pm 2.2\%$). In turn, the females of *F. tritici* were more active than those of *F. occidentalis* (Fig. 6; $F = 5.1$, $df = 1, 22$; $P < 0.034$). *F. tritici* were moving among plant parts $22.9 \pm 8.0\%$ of the time compared with $7.2 \pm 1.3\%$ of the time for *F. occidentalis*.

Although no difference was observed between the feeding behaviors of *F. occidentalis* and *F. tritici*, the two species differed in their utilization of host plant resources. *F. occidentalis* females fed almost three times longer ($4.6 \pm 0.4\%$ of the time) than did *F. tritici* females ($1.7 \pm 0.2\%$; $F = 6.70$, $df = 1, 22$; $P = 0.017$). The females of *F. occidentalis* fed on all of the pepper plant parts (i.e., flowers, buds and leaves) (Fig. 6). In contrast, the females of *F. tritici* were observed to feed almost exclusively ($>93\%$ of total feeding time) on the flowers. Feeding sessions lasted from 2 s to ≈ 1.5 min.

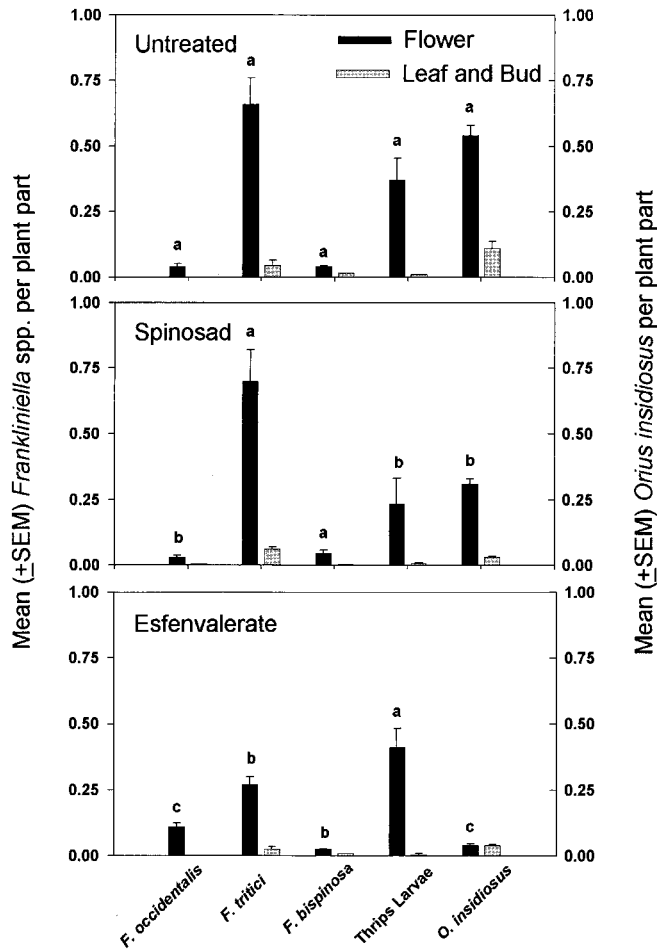


Fig. 3. Mean number (\pm SEM) of *Frankliniella* spp. adults and larvae, and *O. insidiosus* in untreated and insecticide-treated pepper in the experiment conducted during the fall of 1998 in Quincy, FL. For the abundance of each taxon within flowers, insecticide treatment means marked with the same letter are not significantly different ($P > 0.05$, least squares means [SAS 1990]). Data for buds and upper and lower leaves have been pooled for presentation. Data are pooled over all sample dates.

Discussion

The different compositions of *Frankliniella* species found in our study (Fig. 1) reflect geographical differences between northern and central Florida in the dominance of the species, and seasonal differences. Previous studies have reported the abundance of thrips species on crop and wild plant hosts in these two geographical areas. In central Florida, *F. bispinosa* is the predominant species; *F. occidentalis* is present but not abundant, and *F. tritici* is extremely rare (Childers and Beshear 1992, Childers et al. 1998). In northern Florida, *F. occidentalis*, *F. tritici*, and *F. bispinosa* are all abundant, while *F. schultzei* is absent (Salguero-Navas et al. 1991, Chellemi et al. 1994, Toapanta et al. 1996). Also in northern Florida, the proportion of *F. occidentalis* in the species complex becomes extremely low in the fall, and *F. tritici* is the predominant species at that time of year (Ramachandran et al. 2001, Reitz 2002).

Pepper is a reproductive host for *F. occidentalis*, *F. tritici*, and *F. bispinosa* (Funderburk et al. 2000), although

its suitability may differ for each species (Frantz et al. 1995, Nuessly and Nagata 1995). Nevertheless, the difference in species composition between northern and central Florida could not be accounted for by differential reproductive success only. These differences may be attributed either to competition between the *Frankliniella* species or to other factors that regulate population abundance. Seasonal differences in the abundance of these thrips may be related to activity of natural enemies. Ramachandran et al. (2001) showed that local populations of thrips in pepper between late spring and early fall are low because of continued suppression by *O. insidiosus*, and they speculate that populations of *F. bispinosa*, *F. occidentalis*, and *F. tritici* are regulated by this predator during summer and fall in northern Florida. Decreasing daylength, as occurs in the late fall and winter, triggers a reproductive diapause in *O. insidiosus* (Ruberson et al. 1991). This diapause may allow for a resurgence of thrips populations in the spring when adults can be found on many crop and wild plant hosts (Chellemi

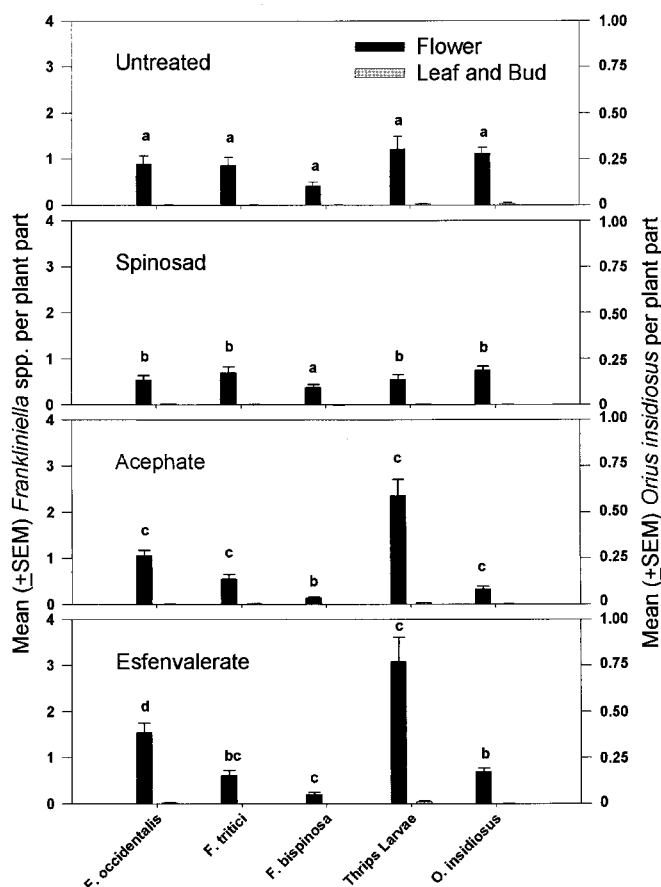


Fig. 4. Mean number (\pm SEM) of *Frankliniella* spp. adults and larvae, and *O. insidiosus* in untreated and insecticide-treated pepper in the experiment conducted during the spring of 1999 in Quincy, FL. For the abundance of each taxon within flowers, insecticide treatment means marked with the same letter are not significantly different ($P > 0.05$, least squares means [SAS 1990]). Data for buds and upper and lower leaves have been pooled for presentation. Data are pooled over all sample dates. Note different scale for *O. insidiosus*.

et al. 1994, Toapanta et al. 1996). In contrast, *O. insidiosus* do not appear to enter diapause during winter in central Florida, which may prevent buildup of *F. occidentalis* populations (Bottenberg et al. 1999). However, *F. bispinosa* may be better able to avoid predation than *F. occidentalis* because of its greater mobility (Ramachandran et al. 2001, Reitz et al. 2002), and therefore its populations are able to persist.

Responses to insecticides also were species-specific. Although significant insecticide by plant part interactions existed, changes in insect abundance were consistently greater for flowers than for other plant parts, most likely as a result of the insects being so concentrated in the flowers. *F. occidentalis* populations were actually higher in plots treated with esfenvalerate or acephate than in untreated plots. This may stem from a combination of insecticide resistance on the part of *F. occidentalis* (Immaraju et al. 1992, Broadbent and Pree 1997) and exclusion of *O. insidiosus* by those insecticides (Funderburk et al. 2000, Ramachandran et al. 2001). Although little is known of the susceptibility of *F. bispinosa* and *F. tritici* to insecticides, our

results suggest that these species are more susceptible to broad-spectrum insecticides than is *F. occidentalis*.

Despite these geographic and temporal differences in the *Frankliniella* species composition and abundance in pepper, and variable responses to insecticides, the within plant distribution of thrips remained constant. Extensive populations of *F. occidentalis*, *F. tritici* and *F. bispinosa* did not develop on the leaves and buds of field pepper in the current study, but large populations were in the flowers. Similar flower-biased distributions for populations of *F. occidentalis* occur in greenhouse pepper (Shipp and Zariffa 1991, Tavella et al. 1996). As our behavioral study shows, adults of *F. occidentalis* and *F. tritici* are able to move throughout a plant, but they have a strong attraction to the flowers. Oviposition may occur, and larvae can develop on the leaves of some plant hosts, such as cucumber (Kiers et al. 2000), but even on such hosts the vast majority of individuals reside in the flowers.

Anthophilous thrips, such as *Frankliniella* spp. use both visual and olfactory cues to locate hosts (Teulon et al. 1993, Terry 1997, Teulon et al. 1999). Low UV

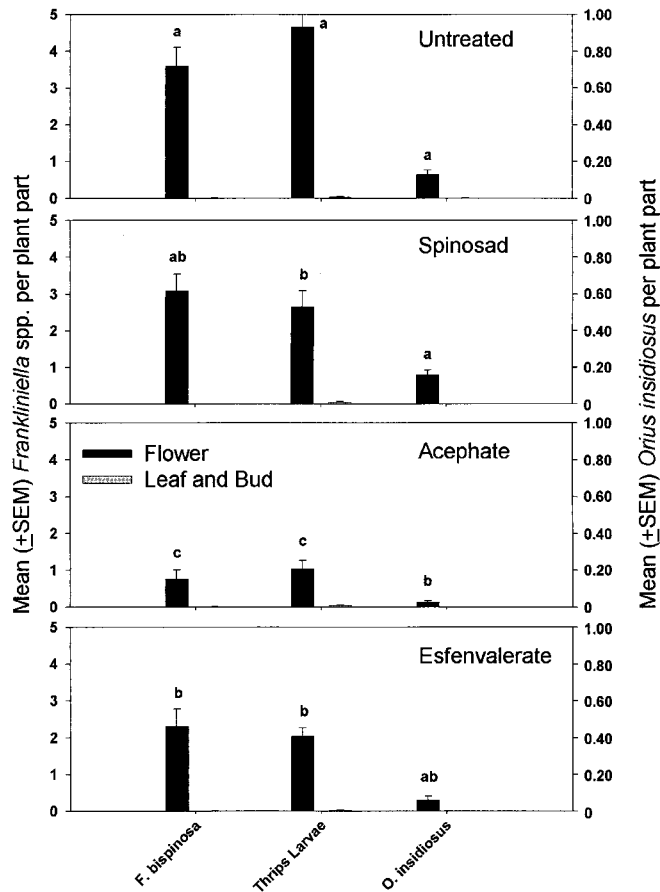


Fig. 5. Mean number (\pm SEM) of *Frankliniella* spp. adults and larvae, and *O. insidiosus* in untreated and insecticide-treated pepper in the experiment conducted during the spring of 1999 in Riverview, FL. For the abundance of each taxon within flowers, insecticide treatment means marked with the same letter are not significantly different ($P > 0.05$, least squares means [SAS 1990]). Data for buds and upper and lower leaves have been pooled for presentation. Data are pooled over all sample dates. Note different scale for *O. insidiosus*.

white, blue, and yellow tend to be the most attractive colors (Kirk 1984). In addition to color, size, shape, and background contrast influence host location. Certain plant volatiles, such as benzenoids and monoterpenes, are attractive to *F. occidentalis* (Teulon et al. 1993, 1999; Koschier et al. 2000). These types of visual and olfactory cues are associated with flowers of many plant species, including peppers.

Adult females of *F. tritici* spent more time than adult females of *F. occidentalis* moving between different plant parts of pepper. These results support the conclusions of Ramachandran et al. (2001) that local movement by *F. occidentalis* between flowers of field pepper was limited, whereas *F. tritici* moved rapidly between the flowers. This rapid movement may assist *F. tritici* in avoiding predation, but adults of *O. insidiosus* also are capable of moving rapidly among pepper flowers. *O. insidiosus* nymphs also must be attracted to flowers. Eggs of *O. insidiosus* are laid mostly on other plant parts of greenhouse pepper (van den Meiracker and Sabelis 1993), yet we found populations of *O.*

insidiosus nymphs and adults were aggregated with their prey in the flowers of field pepper. Shipp et al. (1992) reported the same pattern of aggregation of *O. insidiosus* in the flowers of greenhouse pepper.

The ecological cues that attract *O. insidiosus* to prey-infested patches are not well understood. A portion of prey searching by *Orius* spp. relies on olfactory perception of chemical cues emitted by herbivore-infested plants (Reid and Lampman 1989, VanLaerhoven et al. 2000). Constitutive odors of thrips also are important as prey-searching cues. An alarm pheromone produced by larvae of *F. occidentalis* also is attractive to *O. tristicolor* White (Teerling et al. 1993).

There was no evidence in our experiments that the presence of other thrips species or *O. insidiosus* or insecticides affected the within plant behavior of *F. tritici*, *F. bispinosa*, and *F. occidentalis* on field pepper. While various methods of sampling for thrips are available (e.g., Shipp and Zariffa 1991, Shipp et al. 1998), estimates of populations based on numbers in the flowers of pepper seem to best reflect the local dynamics of these

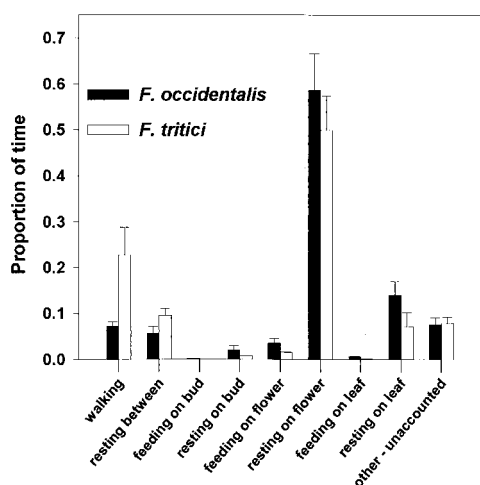


Fig. 6. Proportion of time (mean \pm SEM) spent engaged in different behaviors by adult female *F. occidentalis* and *F. tritici* in laboratory choice experiments.

Frankliniella thrips and *O. insidiosus* in open field situations. This method would be best for assessing the benefits of biological control in scouting programs based on predator to prey ratios (Sabelis and Van Rijn 1997, Funderburk et al. 2000, Ramachandran et al. 2001).

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